FEDERAL EXPERIMENT STATION
of the
United States Department of Agriculture
MAYAGÜEZ, PUERTO RICO

BULLETIN NO. 52

STUDIES ON NUTGRASS (CYPERUS ROTUNDUS L.) AND ITS CONTROL

By
A. J. Loustalot, T. J. Muzik, and H. J. Cruzado

Issued June 1954

UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
OFFICE OF EXPERIMENT STATIONS

FEDERAL EXPERIMENT STATION IN PUERTO RICO

MAYAGÜEZ, PUERTO RICO

Administered by the Office of Experiment Stations

Agricultural Research Service

United States Department of Agriculture

R. W. Trullinger, *Assistant Administrator, Agricultural Research Service, Office of Experiment Stations*

STATION STAFF

Harry E. Warmke, *Officer in Charge.*
Thomas Theis, *Assistant Officer in Charge.*
Harold F. Winters, *Horticulturist.*
Thomas J. Muzik, *Plant Physiologist.*
Murrell P. Morris, *Chemist.*
William C. Kennard, *Horticulturist.*
Leon A. Snyder, *Plant Geneticist.*
Héctor J. Cruzado, *Agronomist.*
Rubén H. Freyre, *Agronomist.*
Jean Garcia Rivera, *Chemist.*
Elida Vivas, *Scientific Aid.*
Félix A. Jiménez Torres, *Collaborating Agronomist.*[1]
Narciso Almeyda, *Collaborating Agronomist.*[1]
Eugenio Cabanillas, *Collaborating Agronomist.*[1]
Rafael A. Garcia Lugo, *Collaborating Agronomist.*[1]
Astor González, *Collaborating Librarian.*[1]

[1] In cooperation with the Government of Puerto Rico.

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 15 cents

FEDERAL EXPERIMENT STATION IN PUERTO RICO

of the

UNITED STATES DEPARTMENT OF AGRICULTURE

MAYAGÜEZ, PUERTO RICO

BULLETIN NO. 52

WASHINGTON, D. C. June 1954

STUDIES ON NUTGRASS (CYPERUS ROTUNDUS L.) AND ITS CONTROL

By A. J. Loustalot, T. J. Muzik, and H. J. Cruzado [1]

CONTENTS

Nutgrass, *Cyperus rotundus* L., a native of the Tropics, is found even in the warmer portions of the Temperate Zone. It is one of the most troublesome perennial weeds of cultivated lands wherever it grows. Vegetables and row crops such as cotton and potatoes are generally more seriously affected by nutgrass than such crops as sugarcane and the cereals. Present methods for eradicating or controlling nutgrass have not been entirely satisfactory because of its efficient manner of vegetative propagation and the rapid growth and deep penetration of its underground rhizomes and tubers.

[1] Formerly Assistant Director and Plant Physiologist, Plant Physiologist, and Agronomist, respectively, Federal Experiment Station in Puerto Rico.

During the past 5 years the Federal Experiment Station at Mayaguez, P. R., has conducted basic studies, some of which have been previously reported (*33*)[2], on the physiology and morphogenesis of the species to find the most vulnerable stage in its life cycle. Field and greenhouse experiments were also conducted with herbicides in an effort to find a practical method of eradicating or controlling this nuisance. The results of these investigations are here reported.

BOTANY AND USES

Nutgrass, or cocograss as it is called in the southern United States,[3] is botanically a sedge. It is a member of the family Cyperaceae of the order Cyperales. The order consists of the one family, which is of worldwide distribution (*25*).

The nutgrass plant has been described as consisting of an underground system of roots, tubers, basal bulbs, and connecting rhizomes, and aboveground of rosettes of leaves and umbel-bearing scapes (*39*). At the junction of the rhizome and leaves, a tuberous enlargement develops, which is termed a basal bulb. A diagram of the plant is shown in figure 1.

There is a close resemblance in structure between the tuber and rhizome. Buds and scale leaves are present on both the young rhizome and tuber; they are lost on the mature rhizome but persist on the tuber. The mature rhizome is a black, wiry strand about 0.3 mm. in diameter that appears lifeless to the naked eye.

The basal bulb is a stemlike structure consisting of a closely appressed series of leaves, sheathing and arising from a tuberous base, and connected to the tubers by a rhizome. It is probable that all buds give rise to rhizomes, some only a millimeter or two long, others several centimeters long. The rhizome may terminate in a basal bulb or a tuber.

The leaves are linear in shape, of the grass-sedge type, about 4 to 5 mm. in width, and up to 40 cm. long. The flower is an inconspicuous panicle that seldom bears fertile seeds. The fruit is an achene. Although each plant is small and seldom bears more than 10 leaves, it may, under favorable growing conditions, form a dense carpet on the soil. The plant gets its common name from the "nuts" or underground tubers which sometimes grow very thickly. In fact, over 1,500 tubers have been found in a cubic foot of Puerto Rican soil.

In Colombia (*11*), as in other countries, nutgrass is considered a weed, but it was readily grazed by cattle. Chemical analyses showed that the nutrient content of nutgrass shoots compares favorably with that of *Panicum purpurascens* Raddi. In some parts of West Africa, *Cyperus rotundus* is regarded as a fodder, and in India the leaves and stems are eaten by cattle and the tubers by pigs. The tuberous rhizome is used as a cough medicine and in the Gold Coast, an infusion of the plant with its roots is given for cattle poisoning (*14, pp. 516–518*). In Puerto Rico, the tubers are ground and boiled with sugar, and the product is sold in the local markets as a kidney medicine or as a soft drink.

---

[2] Italic numbers in parentheses refer to Literature Cited, p. 28.

[3] The common name for this plant in Puerto Rico is "coquí."

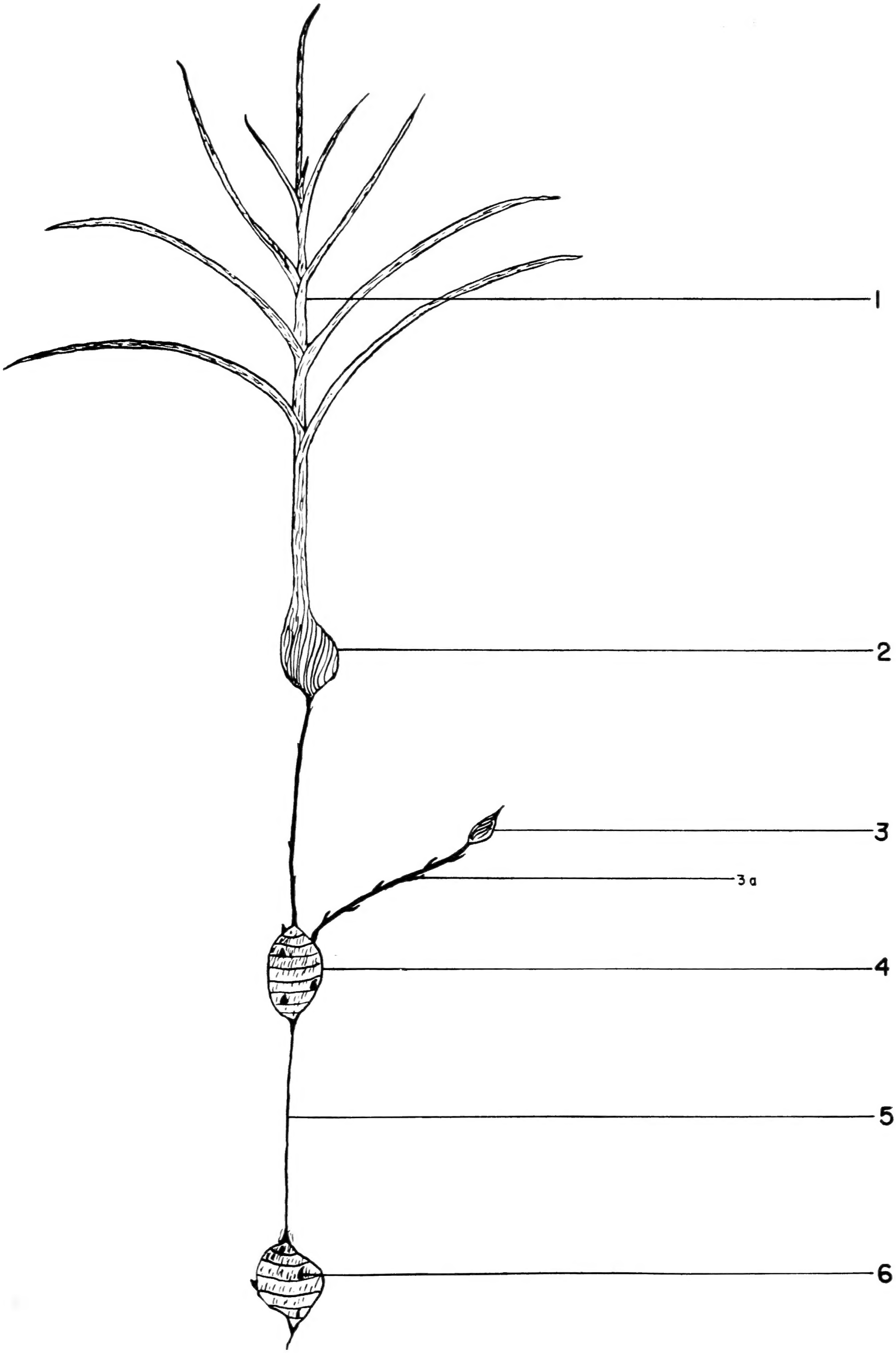

FIGURE 1.—Diagram of nutgrass plant. (1) Shoot, (2) basal bulb, (3) young tuber, (3a) young rhizome with scale leaves, (4) tuber, (5) rhizome, and (6) bud on tuber.

An essential oil which has been used in the preparation of perfumes is also obtained from nutgrass tubers. The oil, obtained by extraction with petroleum ether, is a brown, viscous substance, and has a strong odor similar to a mixture of camphor and pine oil. It consists of a mixture of essential oils and fatty substances that can be separated by steam distillation. The yield of essential oil from India varied from 0.58 to 0.86 percent, whereas yields of 1 percent essential oil are reported from Japan. Nutgrass oil contains about 30 percent alcohols and a large quantity of hydrocarbons. When the oil is distilled under vacuum two main fractions are obtained that have been given the names of Cyperina and Cyperol.

Analysis of the tubers made by the School of Tropical Medicine in Puerto Rico (*4*) showed the following composition: Water 45.95 percent, crude protein 0.71 percent, fat 2.06 percent, carbohydrates 45.13 percent, crude fiber 4.63 percent, and ash 1.52 percent. A monosaccharide in crystalline form has also been isolated.

The only other important weed species in this genus, *Cyperus esculentus* L., the northern or yellow nutgrass, is a serious pest in the northeastern and northwestern parts of the United States. It has been reported in Puerto Rico, but is not common. The "nuts" or underground tubers of this species (chufas, tiger, or Zulu nuts) are edible and are eaten raw or roasted in Africa. Sometimes they are ground and strained and boiled with wheat flour and sugar. A form with large tubers is cultivated in the Gold Coast. In Sierra Leone it is made into a kind of chocolate and is also said to have an aphrodisiac effect (*14*).

STUDIES ON MORPHOGENESIS

Experimental.—Most of the investigations on morphogenesis were done in the greenhouse or laboratory. For these studies, blocks of earth were dug from areas heavily infested with nutgrass. The soil was washed away and the interlacing rhizomes were carefully separated by hand into individual plants. Single tubers or chains of 1 to 14 tubers with connecting rhizomes were used in most of these studies. They were planted in boxes with slanting glass sides (fig. 2). The tubers were laid against the glass so that they were plainly visible. Shutters, painted black on the inside, were slipped over the glass plate. These shutters could be easily removed for visual examination of the plants. Most of these studies were made with sterilized soil to reduce the danger of insect or fungus injury.

Records on early growth were based upon visual observation through the glass plate and final records were taken after removal of the plants. Observations of growing rhizomes and tubers, in situ, against the glass plate showed that tuber formation may be divided into four stages: (1) Elongation of the rhizome from a bud, (2) cessation of growth, (3) expansion of the region just back of the rhizome apex, and (4) new growth of the rhizome, often from the same terminal bud, thus forming a series of tubers separated by varying lengths of rhizomes. Tuber expansion is usually complete before the resumption of growth in length of the rhizome. Tubers are also occasionally formed when a rhizome branches from an axillary bud. Later, thickening occurs at the junction of the rhizome and branch.

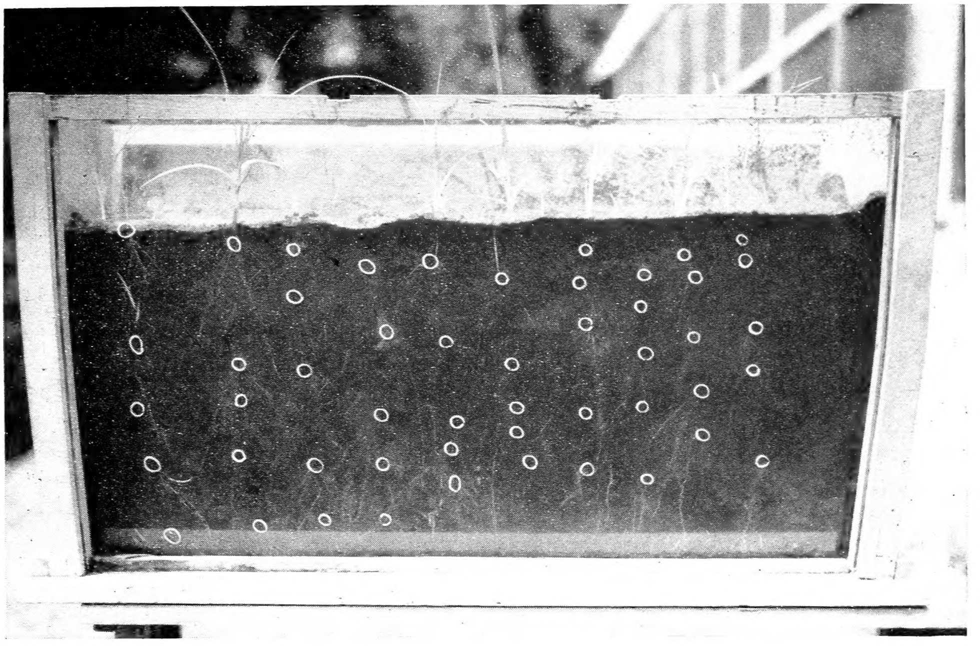

FIGURE 2.—Box with slanting glass sides to show method of planting. Nutgrass tuber systems planted against glass and outlined in white chalk.

New tubers are formed in about 3 weeks after the planted tuber has sprouted. These tubers vary in size from 2.0 to 2.5 cm. in length and 1.5 to 1.8 cm. in diameter. Formation of the basal bulb is very similar to tuber formation, except that the expansion occurs mostly in the apical region. The leaves in the terminal bud thicken and enlarge, and it is from this bud that the shoot emerges. Whether basal bulbs or tubers are formed seems to be conditioned largely by the amount of light. Near the surface, shoots and basal bulbs are formed; beneath the surface, tubers are formed. The length of the rhizome is partially conditioned by light and partially by other factors; rhizomes near the surface are short and terminate in a basal bulb, whereas rhizomes some distance under the soil are of various lengths between tubers, from 2 to 3 mm. to 10 cm. or more.

Distribution of tubers in soil.—Data were obtained on the distribution of nutgrass tubers at 3-inch intervals to a depth of 9 inches in a heavy clay alluvial soil at Mayaguez, P. R. Most of the tubers occur in the first 3 inches of soil. Approximately one-fourth occur in the interval from 3 to 6 inches, and only 3 to 5 percent occur in the 6- to 9-inch depth. Some tubers are found below 9 inches, but seldom do they occur below 12 inches. The number of dead tubers found in the soil samples examined ranged from 5.6 to 14.5 percent.

These data are in general agreement with those from Alabama (*39*) and Arizona (*17*), in which 70 to 80 percent of the tubers were found in the upper 4 inches of soil. The remainder were found to lie at depths down to about 8 inches, but isolated tubers were found as deep as 16 inches.

Regenerative capacity.—One of the most troublesome characteristics of nutgrass, from the standpoint of its control, is the ability of the tuber to send up sprouts over long periods of time. A count of 20

tubers showed an average of 8 to 10 buds per tuber which would be the maximum number of sprouts possible, unless adventitious shoots are formed. A number of experiments were carried out to determine whether the nutgrass tuber has the ability to develop adventitious buds or whether sprouting is only from preformed axillary buds.

Tubers were scraped clean of epidermis and buds and were placed in petri dishes on filter paper moistened with distilled water. Although they remained in the dishes for nearly a year, no buds were regenerated, and only an occasional root was formed. Tubers were sectioned frequently and always appeared healthy with firm white tissues.

Tubers were cut in half and treated on the cut surface with a number of different chemicals in an effort to induce callus growth or adventitious bud formation. No buds were induced, nor was the pattern of "healing" changed (*33*). Sprouting occurred only from preformed axillary buds. The number of sprouts from a tuber is apparently limited. Therefore, if all the axillary buds can be induced to sprout and then are killed, there is no danger of extensive adventitious bud proliferation such as occurs in some plants.

Propagation from seed.—Nutgrass seeds are produced throughout most of the year in Puerto Rico. Several germination trials were made, some with mechanical or chemical scarification. The seeds were allowed to remain in sterile sand for 6 months to a year. Only one seed germinated out of several thousand tested. In extensive trials with nutgrass seed, Justice and Whitehead (*26*) reported that the seeds require an afterripening period. Maximum percentages of germination of the heavy seed fractions ranged from 10 to 18. From a total of 13,430 heavy seeds tested, 4.1 percent normal and 1.7 percent abnormal seedlings were obtained. Actual seed counts showed that a minimum of 4.8 inflorescences would be required to yield a single seedling. There was no correlation between the number of seeds containing embryos and the percentage of germination, but there was an apparent correlation between the number of seeds with large embryos and percentage of germination. Justice and Whitehead concluded that reproduction by seeds was relatively unimportant in the southern part of the United States, which is in agreement with our studies in Puerto Rico.

Sprout formation in single tubers.—Nutgrass tubers were placed in damp, dark chambers. Some tubers were left intact and placed vertically, horizontally, or inverted, using modeling clay as a base to hold them in place. Others were cut vertically and horizontally through the center. Ten tubers were used in each treatment, and were studied individually for sprouting. The apical bud sprouted first on whole or top halves of tubers in every instance. On the bottom halves, the buds nearest the cut surface, i. e., nearest the apical bud, were first to grow. 2,4-D in lanolin at 1.0, 0.02, and 0.01 percent inhibited sprouting when applied on top of vertically placed tubers, but it did not inhibit sprouting on inverted tubers. When applied on the base of vertically placed tubers, 2,4-D had no effect.

Similar experiments were conducted in daylight. Under these conditions, the apical bud usually sprouted first and the total number of buds that sprouted was much greater than when the tubers were grown in the dark. These experiments demonstrate the strong domi-

nance of the apical bud over the lower buds on the tuber and the effect of light in inducing sprouting. The effect of light on sprouting is discussed in more detail on p. 9.

An experiment was designed to determine whether polarity was strong enough to cause a definite sequence of sprout formation when the tubers were separated from the system. Five nutgrass chains of 5 tubers each were dug from the soil. The tubers were separated from the system, planted in 3-inch pots, arranged in a 5 x 5 Latin square, and time of germination was recorded. There was no statistically significant difference in the time of germination of separated tubers, regardless of the position they formerly occupied in the system. Similar results were obtained with chains of four. When tubers in chains were freed from the dominance of the top tuber they began to grow at equal rates. This is an important fact to consider in planning treatment to control nutgrass. If the tuber systems are adequately broken up by plowing prior to treatment, the tubers will sprout at the same time and be equally susceptible to the herbicide.

Sprout formation in intact chains.—In all of the experiments with intact chains planted vertically, sprouting usually occurred only in the topmost tuber and only occasionally in other tubers (*33*).

In a typical experiment, single tubers and chains of 2, 3, and 4 were selected and planted in a vertical arrangement using 10 in each set. Approximately 15 mg. of lanolin containing 1 percent 2,4-D was applied to the top tuber only of half of these plantings.

In the untreated systems sprouts were formed on the topmost tubers in 20 days after planting, whereas sprouting was completely inhibited in the treated ones. Root formation occurred in about 5 days on both treated and untreated tubers, regardless of their position in the system. Root elongation was very rapid and occurred at about the same rate on all tubers.

Death of the roots on the treated tubers was first observed 30 days after planting. A week later, all of the roots on the first and second tubers in the treated chains were dead, whereas those on the third and fourth were still apparently healthy. Five days later the roots on the third tubers of treated chains were also affected, whereas all of the roots on the controls appeared healthy.

In other experiments, chains of 2, 3, 4, and 5 tubers were aligned horizontally, or vertically, with the morphologically top one on the bottom. On one half of these chains the topmost tuber was treated with approximately 15 mg. of 1 percent 2,4-D.

At the end of 10 days, many of these tubers had produced roots regardless of inversion, position, or treatment, and the sprouting in the various systems was nearly equal, regardless of position or treatment in either the horizontal or inverted chains. Some of these results are shown in figure 3. There was no inhibition of sprouting such as occurred when the chains were placed in their normal position or in vertical arrangement.

Effect of killing rhizome tissues.—Since it was apparent that sprouting of the lower tubers in a system was inhibited by the apical dominance of the top tuber, and since inhibition of buds on other plants may be overcome by injuring the stem, it was decided to test the effect of killing the rhizome tissues, which serve as the only

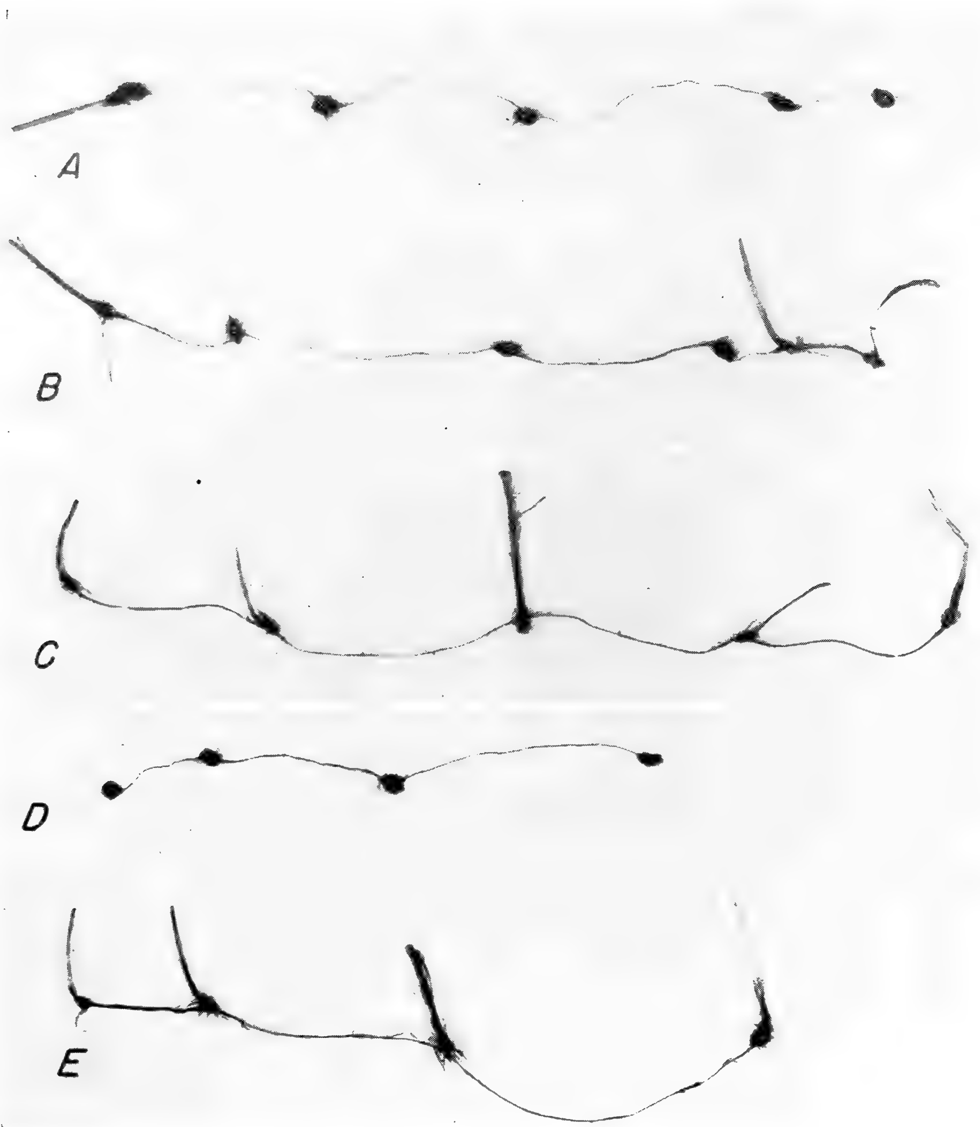

FIGURE 3.—Sprouting in tuber systems as affected by arrangement and treatment with 2,4-dichlorophenoxyacetic acid. *A*, Vertical arrangement; only top tuber sprouted. *B*, Inverted arrangement; 3 tubers sprouted. *C*, Horizontal arrangement; 5 tubers sprouted. *D*, Vertical arrangement plus 2,4-D on top tuber only; no sprouting. *E*, Horizontal arrangement plus 2,4-D on top tuber; all tubers sprouted. Sprout on top tuber was later killed.

connecting links between tubers. Twenty-three intact systems consisting of from 4 to 10 tubers were carefully dug and washed. The rhizomes were given the following treatments: (1) Placed in boiling water for 30 seconds, (2) in boiling alcohol for 30 seconds, or (3) in boiling alcohol for 3 minutes. Only the rhizome was treated; the tubers were left intact and did not come in contact with the hot water or alcohol.

Placing the rhizomes in boiling water or boiling alcohol for 30 seconds to 3 minutes resulted in the sprouting of all of the tubers in

the chain. Some of the treated chains had as many as 10 tubers, all of which sprouted at the same time as the separated ones.

A similar experiment was conducted to determine whether 2,4-D would translocate in the treated and presumably killed tissue of the rhizomes.

Nutgrass systems were planted in a vertical arrangement. One group of 6 chains was left untreated, the rhizomes of a second group of 6 chains were treated for 60 seconds in boiling water previous to planting, and the rhizomes of a third group were treated in a similar manner and, in addition, approximately 15 mg. of 1-percent 2,4-D in lanolin was applied to the top tuber.

The results obtained 1 month after treatment are shown in table **1.**

In the untreated chains, sprouting usually occurred only on the topmost tuber. In the chains with killed tissue in the rhizomes, nearly all the tubers sprouted, and in the 2,4-D-treated chains with killed rhizomes, sprouting was inhibited only on the top tuber. Most of the lower tubers sprouted and there was no death of either roots or sprouts, showing that the applied 2,4-D failed to translocate through the killed tissues of the rhizome.

TABLE 1.—*Sprouting of tubers in intact chains after treatment to kill rhizome tissue and the addition of 2,4-D to top tubers only*

Treatment	Tubers	Chains	Sprouted	Sprouts	Top tubers sprouted
	Number	*Number*	*Number*	*Percent*	*Number*
Control	24	6	8	33. 3	5
Rhizomes killed	27	6	22	81. 5	5
Rhizomes killed+2,4-D	26	6	16	61. 5	0

Sections made of untreated mature rhizomes contained healthy phloem tissue consisting of well-developed sieve tubes and companion cells. Parenchyma cells are located primarily in the center of the rhizome but are also scattered among the vascular bundles (fig. 4). These cells are normal in appearance, resembling the parenchyma cells of the tuber. They also contain large quantities of starch grains. Since auxin transfer occurs only in living tissue, the presence of living cells even in the mature rhizome suggests that the apical tuber exerts its dominance by auxin transfer through these cells. Killing these cells prevents the movement of natural or applied auxin and releases the lower tubers from the dominance of the top tuber.

Effect of light on sprouting.—Since light is known to affect sprouting in plants, an experiment was carried out to test its effect on nutgrass. Five chains of 6 tubers each were planted in a box with slanting glass sides so that they were pressed tightly against the glass by the soil in the box. Thus, the tubers and rhizomes were kept moist by the soil but were exposed to light during the day. A similar set was planted in darkness as a control. Extensive sprouting of buds occurred in the tubers exposed to light. When they were removed from the soil and examined 1 month later, it was found that 16 out of 26

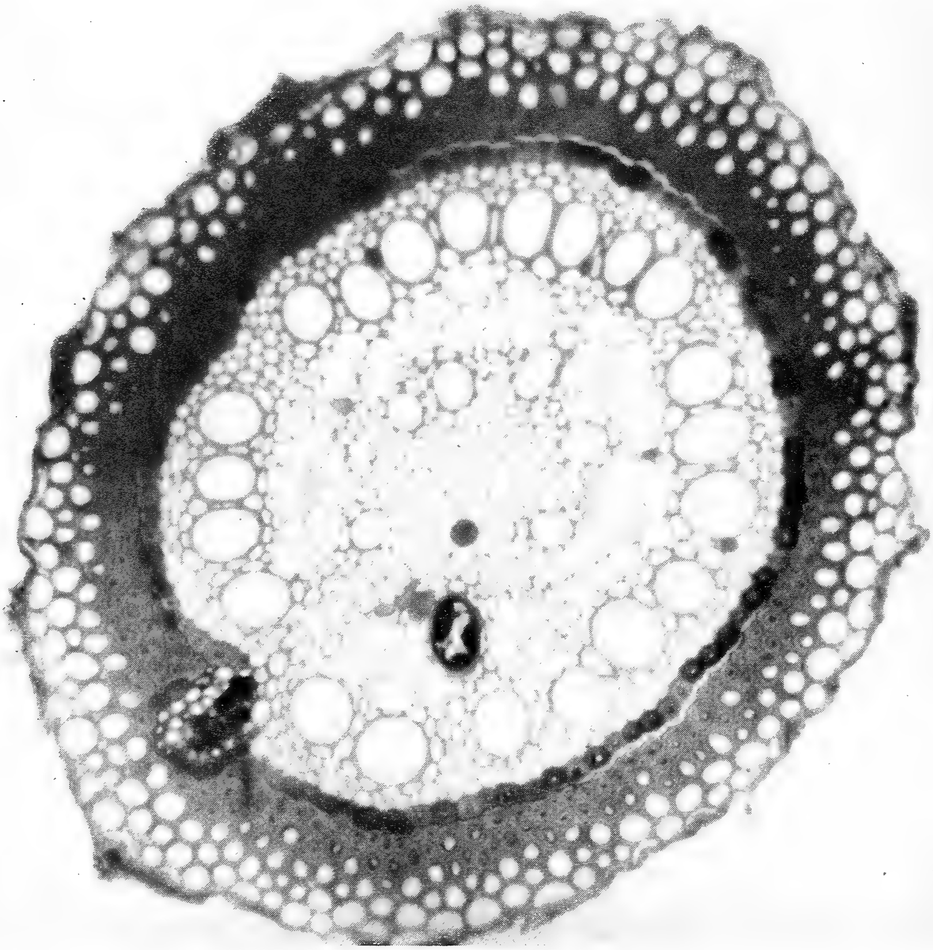

FIGURE 4.—X-section of nutgrass rhizome, showing thick schlerenchyma sheath, pericycle, endodermis, xylem, phloem, and central pith.

tubers had germinated, with an average of 5 shoots per tuber, indicating that light destroyed apical dominance both in the system and in the tuber (fig. 5). Only 7 tubers out of 24 sprouted in the controls, and these had only 1 sprout each.

The foregoing fundamental studies show that in many respects nutgrass resembles other, more "typical" plants. For example, dominance of the apical tuber over lower tubers in the same system may be likened to the dominance of the apical bud over the other buds on a typical shoot. Inducing sprout formation on the lower tubers by heat treatment of the interconnecting rhizome is similar to girdling the stem of dicotyledonous plants to induce bud growth, in that, in both instances, the phloem and cortical parenchyma are killed or removed. The nature of sprout formation suggests that methods of control should consist of treatments designed to disturb the underground systems as much as possible, i. e., break the chains and bring the tubers near to the surface, etc. The tubers will sprout more uniformly and may then be killed by herbicidal treatment.

Our experiments indicated that the most vulnerable period in the life history of nutgrass is within the 3 weeks after the first sprouts

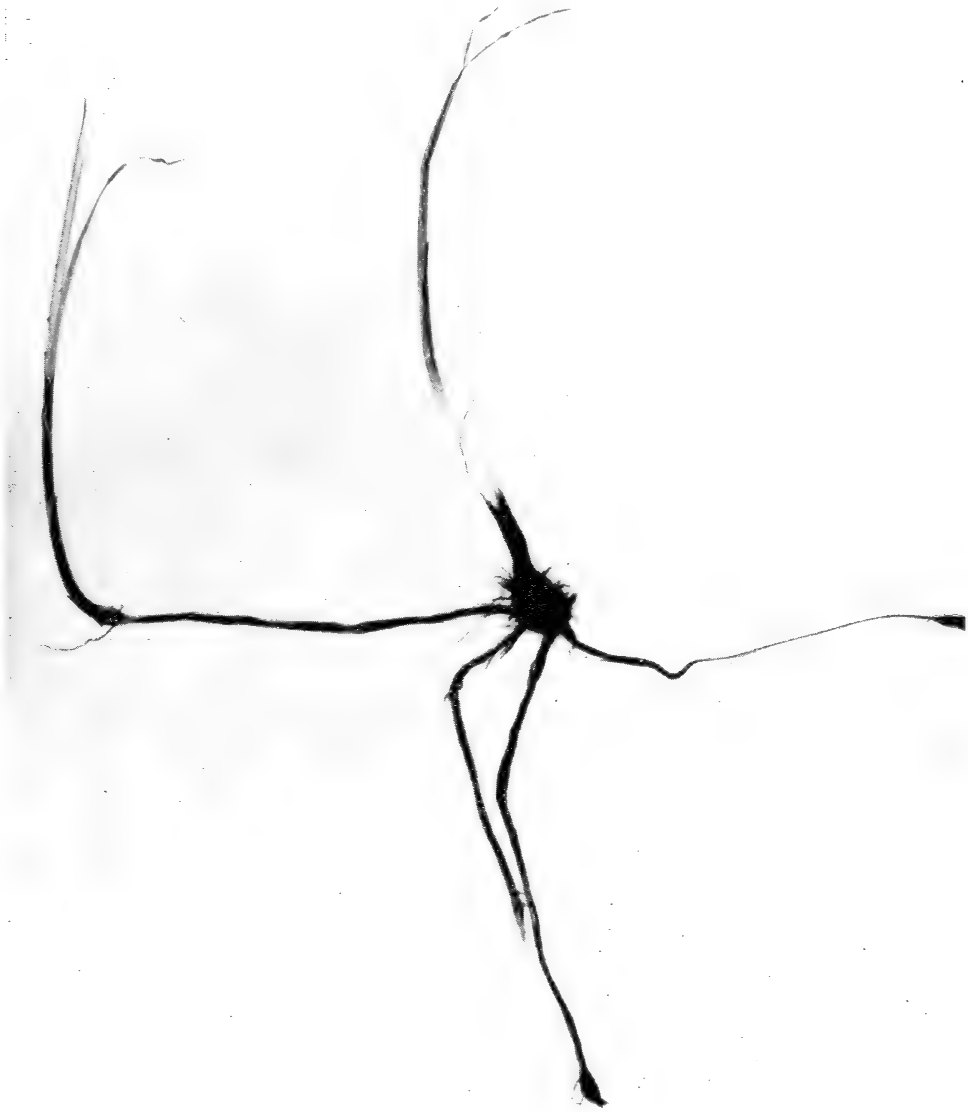

FIGURE 5.—Numerous sprouts produced by nutgrass tuber exposed to light, demonstrating that light destroyed the apical dominance. Tubers planted in darkness usually produced only one sprout which grew from the apical bud.

appear. Treatment of the sprouts should be made at this time, since it is during this period that rapid growth is occurring and no new underground tubers have yet been formed.

METHODS OF CONTROLLING NUTGRASS

Since nutgrass is a serious menace to agriculture in large areas of the Tropics and subtropics many different methods have been tried to control and eradicate the pest. The methods tried to date have generally resulted in varying degrees of success. Complete eradication has seldom been achieved, and the methods that have been successful are usually too expensive or time-consuming to be used on a large

scale. Some of the more important methods that have been used to combat nutgrass at this station and elsewhere are described below.

The use of livestock for controlling nutgrass is recommended in Queensland (*50*). Pigs will root out the tubers if they are permitted to do so and poultry will pluck all the young shoots so that an area will be nearly clean within a couple of years (*3*). However, in Alabama (*32*) chickens were effective in eradicating nutgrass only on small areas and when they were sufficiently numerous to keep the leaves eaten to the ground. Geese effectively controlled nutgrass in half-acre areas cropped to cotton but not on uncropped land.

Parasitic insects of nutgrass such as coccids and mealybugs (*44*) do not seem to exercise any great control. Such insects exist in Australia and Hawaii and have also been tested in Fiji (*36*). Only the moth *Bactra* from Hawaii gave some measure of control.

In Fiji (*15*), in Puerto Rico, and elsewhere, nutgrass is not a major pest of sugarcane, cotton, and corn, except during the early stages of growth. It is, however, a serious pest of root crops, such as potatoes and peanuts, and of crops that are not cultivated, like dryland rice. In small plots nutgrass may be eradicated by digging up and burning the roots and tubers, but it is a laborious and expensive method and is impracticable on a field scale.

In the Sudan (*2*) cutting the root system below the depth of the lowest tuber and allowing the severed tubers to remain in the dry soil for at least 1 month is recommended as a measure of control. In Arizona (*16*, *17*) it was demonstrated that there is a direct relationship between nutgrass eradication and moisture supply. Experiments with potted plants showed that when the soil moisture decreased 2 percent below the moisture equivalent, tubers as well as tops decreased in weight. The tuber-to-top ratio was higher than average when soil moisture minimum was below the wilting coefficient. Eradication by drying was effected in 2 years by bringing the tubers near the surface through successively deeper plowing at intervals of 2 to 3 weeks during midsummer.

Similar experiences are reported from Alabama (*39*, *40*, *41*) where it was found that the tubers of nutgrass are readily killed by drying and by exposure to sunlight. A temperature of 60° C. or over killed the tubers in 1 hour, but at lower temperatures much longer exposure was necessary. Freezing for 8 hours had no effect on viability. Nutgrass was completely eradiacted from a sandy loam soil by plowing or disking at intervals of up to 3 weeks during 2 consecutive seasons. The infestation was reduced about 80 percent by the first year's treatment. The same tillage was applied to 10 different soils with the same result. Plowing with a scrape produced the same results as plowing with the turnplow. Tubers below plow depth survived and the remaining ones could be dug up as they sprouted. The method was not suitable on permanently moist soils.

Mechanical methods of control, other than digging, are considered ineffective in Australia (*42*) and other countries where cultivation of the soil in many cases only resulted in spreading the tubers further. In Queensland (*50*) it was found that cultivation at frequent intervals reduced the competition from nutgrass but did not eradicate it. The possibility of eradicating nutgrass by deep cultivation was demonstrated in India (*1*). In one case success was achieved when the land

was kept fallow for two seasons and cultivated fortnightly (*43*). The same method is also recommended in Thailand.

In a few cases (*3*, *50*) frequent flaming or burning has been successfully used to combat nutgrass, and in Fiji (*15*) the weed was readily controlled and soon eradicated by prolonged flooding of the infested land.

In Mississippi (*28*) applications of LHH–1 (naphtha oil) at a rate of 2.5 gallons per acre did not affect nutgrass. Talley (*45*) found that spraying the soil and basal stems with naphtha oils having an aromatic oil content of 23 to 25 percent and a boiling range of about 300°–400° F., gave excellent control of nutgrass shoots but not of tubers.

Experiments with 2,4-D.—Hormone treatments, mainly of the 2,4-D type, have been used by several investigators for combating nutgrass. Buckley in Malaya (*5*) pointed out that such treatments can have the reverse effect to that intended, since the 2,4-D resistant grasses benefit from the destruction of competing species. This has actually happened in sugarcane fields in Puerto Rico. The constant use of 2,4-D has eliminated most of the broad-leaved weeds and has created a more serious weed problem with the perennial grasses.

In Tucumán, Argentina (*19*) 2,4-D was applied at different stages of development, in concentrations ranging from 0.03 to 0.3 percent. The effect on the foliage and stems was satisfactory on the whole, a "kill" in some cases of 95 percent and over being obtained within 20 days after treatment. The action of the 2,4-D generally penetrated as far as the growing point, 5 cm. below the surface, but the great majority of the tubers were unaffected. In Louisiana (*12*), 2 pounds per acre of 2,4-D amine salt caused rapid kills of the tops and some of the basal nuts but did not materially reduce the number of nuts in the soil. Applications of a mixture of 2,4-D amine salt and sodium trichloroacetate (TCA) did not give significantly better control than either herbicide used alone.

West (*49*) reported from Florida that wetting nutgrass with 2,000 parts per million (p. p. m.) of either the ethyl ester or the sodium salt of 2,4-D, eradicated 90 percent of the nutgrass sprouts on heavily infested plots, although loose, dormant nuts were not affected. Harrison (*24*), Burgis (*6*), and Burgis and Spencer (*9*) found that applications of 4 pounds or more per acre killed the tops, especially with repeated sprayings (*7*, *8*).

The use of 2,4-D has been recommended as a control measure for nutgrass in sugarcane (*46*, *47*) either alone or in combination with an herbicidal oil (*34*), although other workers (*12*, *13*, *29*) found no permanent reduction in stand or satisfactory control from this chemical nor has it proved effective on northern nutgrass, *Cyperus esculentus* L. (*35*).

Eames (*20*, *21*) found that when nutgrass was treated with a growth-regulating substance of the 2,4-D group, the stimulus given by the substance was immediate and brief, and that there was no later stimulus without further treatment. Some tissues and parts of organs (e. g., the leaves) were stimulated to mature at once in abnormal form; other tissues (e. g., in the stems) became abnormally meristematic under the stimulus and formed abnormal tissues continuously for some time or as long as the organ lived. New tissues and organs formed after treatment were not affected.

Evidence gained during the studies on the life history of nutgrass suggested that it could be controlled by upsetting the natural auxin relationship, i. e., overcoming the dominance of the top tuber and thus inducing more tubers to sprout. Tubers can be treated effectively with an herbicide after they sprout by inverting or breaking up the chain, or by bringing the tubers to the surface.

The following experiment was designed to test this theory under field conditions. Two adjacent areas heavily infested with nutgrass were divided into 6 plots, each 22 x 17 feet, and 1 area was thoroughly plowed and disked. Three plots in each area were left untreated, and 3 were treated with 5 pounds per acre of the isopropyl ester of 2,4-D.[4] Previous work had shown that formation of new tubers began about 3 weeks after sprouting, hence, spraying was done about 18 to 21 days after the first sprouts appeared. The undisturbed plots were sprayed at the same time. One month after spraying the plowed plots were again plowed, and 3 weeks later both plowed and unplowed areas were sprayed again with 2,4-D at the rate of 5 pounds per acre. The same procedure was repeated 6 times at intervals over a period of 16½ months.

Tubers were counted in a square foot sample taken to a 9-inch depth from each plot before treatments were applied and 1 month after the second and subsequent sprayings. A reduction of 89 percent of live tubers occurred in the plots that were both plowed and sprayed 16½ months after the experiment was initiated and after the sixth spray treatment. The tubers increased about 68 percent in plots that were plowed only (to as high as 1,615 tubers in a sample block). The number of tubers in plots that were unplowed and sprayed was reduced about 67 percent, and in the unplowed-untreated plots, a reduction of 55 percent occurred. No nutgrass sprouts were visible, however, in the unplowed plots after the second spray treatment because Bermuda grass (*Cynodon dactylon* L. Pers.) covered them completely. On the other hand, there was relatively little Bermuda grass but a considerable number of nutgrass shoots in the plowed areas; consequently, a superficial examination of the experimental area might have led to the erroneous conclusion that control was most effective on the unplowed land. The percentages of tubers remaining after each spray application are shown graphically in figure 6.

Although the reduction of nutgrass tuber infestation in this experiment has been insufficient to date to consider any of the treatments as a practical method of eradication (since even 11 percent of the tubers would be sufficient for reinfestation), the results substantiate the theory that nutgrass tuber population can be reduced more effectively by inducing maximum sprouting before treatment with 2,4-D.

This experiment also demonstrates that a treatment such as plowing, which is effective under dry climatic conditions in Arizona (*17*), is ineffective under humid conditions and may actually increase the infestation as it did in this instance. It also shows the ability of tubers to survive in the soil for long periods without sprouting and the necessity of making counts of the tubers rather than relying on visual examination of the sprouts alone.

---

[4] All 2,4-D weights indicated in this bulletin are on an acid equivalent basis.

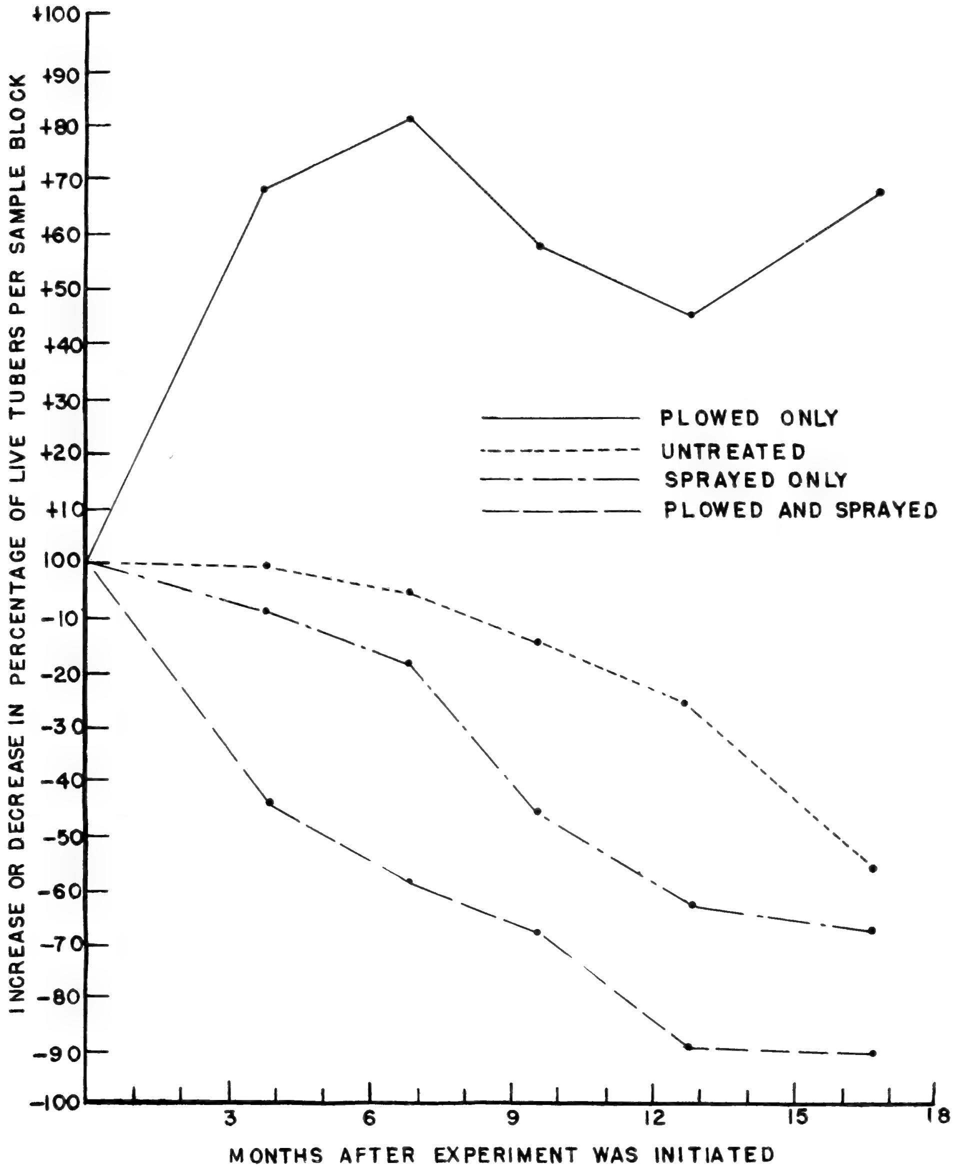

FIGURE 6.—Percentage of live nutgrass tubers remaining after each treatment with 2,4-D. Last count made 16½ months after the experiment was started.

Combination of 2,4-D and pentachlorophenate.—Preemergence weed-control experiments indicated that combinations of 2,4-D and pentachlorophenate (PCP) significantly reduced nutgrass populations. An experiment was conducted to test repeated applications of these herbicides alone and when combined. Five replications of the following treatments were applied to a plowed and disked area heavily infested with nutgrass: (1) PCP at 30 pounds per acre alone, (2) with 5 pounds of sodium 2,4-D, (3) PCP at 60 pounds per acre alone, (4) with 10 pounds of sodium 2,4-D, (5) sodium 2,4-D alone at 5 pounds per acre, and (6) at 10 pounds per acre.

Six weeks later a second application of herbicides was made to 4 replications of each treatment, and 1 month later a third application was made to 3 replicates of each treatment. Plots treated with PCP and 2,4-D at the high or low rate either alone or combined were free of all vegetation for about 1 month after the last application. Bermuda grass then gradually spread over the area until all the treated plots were completely covered with this species.

In the meantime the check plots became heavily infested with nutgrass. Examination of the soil to a depth of 12 inches, 2 months after the last application, showed that there were some live tubers present in all the treated plots, and there were no appreciable differences in the effectiveness of any of the treatments. Either 2,4-D and PCP alone or combined at the rates tested (5 pounds 2,4-D; 30 pounds PCP per acre) applied at monthly intervals for 3 months were equally effective as the high rates in killing nutgrass shoots and in reducing but not eradicating the dormant tubers. This experiment also demonstrates that the suppression of one weed pest such as nutgrass may result in the substitution of another weed such as Bermuda grass.

2,4-D and smother crop.—In Fiji (*36*) satisfactory control of nutgrass has been achieved by growing a green manure crop. In the Turkoman Soviet Republic (*31*) the use of alfalfa in rotation with cotton was found to reduce considerably the stand of nutgrass. *Panicum maximum* Jacq. has been used with some success as a biological control measure in Hosur, India (*37*). It persists in the field for several years and eradicates the nutgrass by smothering it. In Tucumán, Argentina (*38*), it is recommended that farmers and especially citrus growers raise *Stizolobium* spp. to check the growth of nutgrass.

The following experiment was conducted at this station in an attempt to eradicate nutgrass with repeated applications of 2,4-D followed by a smother crop after the 2,4-D had dissipated.

An area heavily infested with nutgrass was divided into 18 plots 30 x 15 feet and grouped into 3 series, each containing 6 plots. Within each series, 2 plots were designated as checks, 2 received sodium 2,4-D at 1.3 pounds per acre, and 2 received 2,4-D at 2.6 pounds per acre. On one series of plots the 2,4-D was applied for a month at 2-week intervals and was followed by tillage; and similar treatment was applied to another series for 2 months, and to the third series for 3 months. Velvetbeans (*Stizolobium deeringianum* Bort.) were planted as a smother crop 2 weeks after the last 2,4-D application in each series. Because of a drought during the experimental period, the velvetbeans failed to germinate in any of the plots, including the controls, until heavy rains stimulated the growth of both the velvetbeans and nutgrass.

Six months after the experiment was initiated, and about a month after the rains started, all treated and check plots were heavily infested with nutgrass. A large percentage of the velvetbean seed had also germinated and the entire experimental area was soon covered with a vigorous growth of velvetbean vines. The nutgrass became yellow and unthrifty and was eventually shaded out by the velvetbeans. When the velvetbeans were plowed under later to make space for other experiments the nutgrass grew as vigorously as before.

The poor results with 2,4-D in this experiment were attributed to the fact that after it was applied it was plowed into the soil which

apparently diluted it too much. In the previous experiments 2,4-D was applied after the land was prepared. This provided a thin film of the herbicide which the nutgrass shoots contacted when they emerged from the soil.

This experiment demonstrates that vigorous leguminous cover or forage crops such as velvetbeans can be grown successfully without mechanical or chemical weed control, in areas heavily infested with nutgrass. If adequate soil moisture is available the legume competes successfully with the nutgrass by shading out and temporarily suppressing it.

Clonal resistance studies.—Conflicting results have been reported in controlling nutgrass with 2,4-D. These may be accounted for by the presence of resistant strains that could conceivably exist in different numbers in different areas. Treatment with 2,4-D might kill off the susceptible ones and leave the resistant strains to multiply. To test this hypothesis nutgrass tubers were obtained from various areas of Puerto Rico and were tested for resistance to 2,4-D.

Tuber samples were obtained from the station grounds and from heavily infested areas in various parts of the island. Most of the clones from the station grounds were from areas that had previously been treated several times with 2,4-D. Thus, any susceptible strains would presumably have been killed although the resistant strains would have multiplied and would be more likely to occur in these samples. Blocks of earth approximately 1 cubic foot in volume were dug and washed to remove the nutgrass systems intact. Each chain of tubers was treated as a separate clone and was multiplied by dividing each tuber into four pieces. Each piece was planted individually in a small container on the greenhouse bench. Three weeks after the shoots emerged they were sprayed with 0.3 percent 2,4-D acid (ammonium salt) which has been recommended for killing nutgrass (*46*, *48*). There were 10 replications of each clone.

Death of the sprouts occurred in all treated plants, regardless of origin, over a period of 3 weeks after treatment. Plants treated when 3 weeks of age, or younger, showed no signs of recovery. Treatment of older plants of the same clones also resulted in death of the sprouts, but new growth often occurred from underground tubers. It was found that plants 3 to 4 weeks old began to produce new underground tubers which sprouted after the top was killed. These results suggest that resistance to 2,4-D is not a clonal characteristic. They also substantiate the observations made previously that the ability of nutgrass to recover from treatment with 2,4-D stems from the fact that only the sprouts and top tubers are killed, whereas the tubers further down the chain are not.

In other experiments carried out at this station it was found that 2,4-D was more effective if it was applied after the ground had been plowed than if it was applied first and then mixed with the soil. Also better control of nutgrass was attained if the 2,4-D was applied a week or more after the land had been plowed. Temporary control of nutgrass shoots in corn and sugarcane was achieved by spraying with 0.2 percent 2,4-D. The ester formulation was more effective in killing the shoots and basal bulbs than were the sodium or amine salts, but the salt formulations were better for killing the tubers in plowed soil.

Experiments similar to the foregoing ones with 2,4-D were also conducted with 2,4,5-trichlorophenoxyacetic acid. The chemical proved less effective on nutgrass than 2,4-D.

Maleic hydrazide at 12 and 20 gallons per acre was ineffective in reducing the number of live tubers.

Experiments with fumigants.—Soil fumigation with chloropicrin was found to be an effective means of eradicating nutgrass in Texas (*23*), but this method was too expensive for large-scale field application. Calcium thiocyanate was reported to eradicate nutgrass at the rate of 1,400 pounds per acre (*22*). Day (*18*) has suggested the use of chlorobromopropene as a treatment for small areas of infestation. Leonard and Harris (*27*) reported that applications of 1, 2, and 4 pounds of methyl bromide per 100 square feet, made to loose soil covered with vaporproof sisalcraft paper, caused 100 percent tuber mortality. On heavy compact soil results were unsatisfactory.

In São Paulo Shell D–D (a mixture of 1,2-dichloropropane and 1,3-dichloropropylene) was found to give more efficient control than Dowfume W–10 (10 percent ethylene dibromide). Applications were most efficient when made at the rate of 15 ml. per 30 x 30 cm. spacings. It is recommended that an interval of 20 to 30 days be allowed to elapse after treatment and before planting, in order that the fumigant may dissipate and not injure the crop. Carbon bisulfide at 4,500 pounds per acre was also reported effective (*10*).

Three of the most promising fumigants—chloropicrin, ethylene dibromide, and methyl bromide—were tested for nutgrass control in the following experiment at this station.

Two of the fumigants, chloropicrin and ethylene dibromide, were each tested at the rate of 3, 6, and 12 ml. per square foot. The fumigants were applied in furrows about 6 inches deep and 6 inches apart to plowed and disked land. The furrows were then covered with soil and the fumigant sealed by watering the soil.

Ethylene dibromide applied at 6 ml. per square foot was almost as effective in eradicating nutgrass as was the 12 ml. rate, but at 3 ml. the control was poor. Plots treated with 3, 6, and 12 ml. of chloropicrin per square foot developed a luxuriant stand of nutgrass. This fumigant not only failed to control the nutgrass under the conditions of the experiment but at the low concentration seemed to stimulate it. The poor results with chloropicrin may be attributed to the fact that a water seal was used instead of a gasproof cover. Most of the fumigant probably escaped after the water evaporated. Figure 7 shows representative plots of each treatment 4 months after application.

Ethylene dibromide may have been more effective than chloropicrin under the conditions of this experiment because it has a greater density, and diffusion out of the soil was probably slower.

Although the ethylene dibromide at 6 and 12 ml. per square foot eradicated nutgrass, it does not appear practical for use on a large scale because of the high cost of the material.

Since Leonard and Harris (*27*) reported good results in eradicating nutgrass in Mississippi by fumigating the soil with methyl bromide, this method was tested under Puerto Rican conditions.

A level area of Toa silty clay loam heavily infested with nutgrass was divided into 8 plots, 6 plots 10 x 10 feet and 2 plots 10 x 20

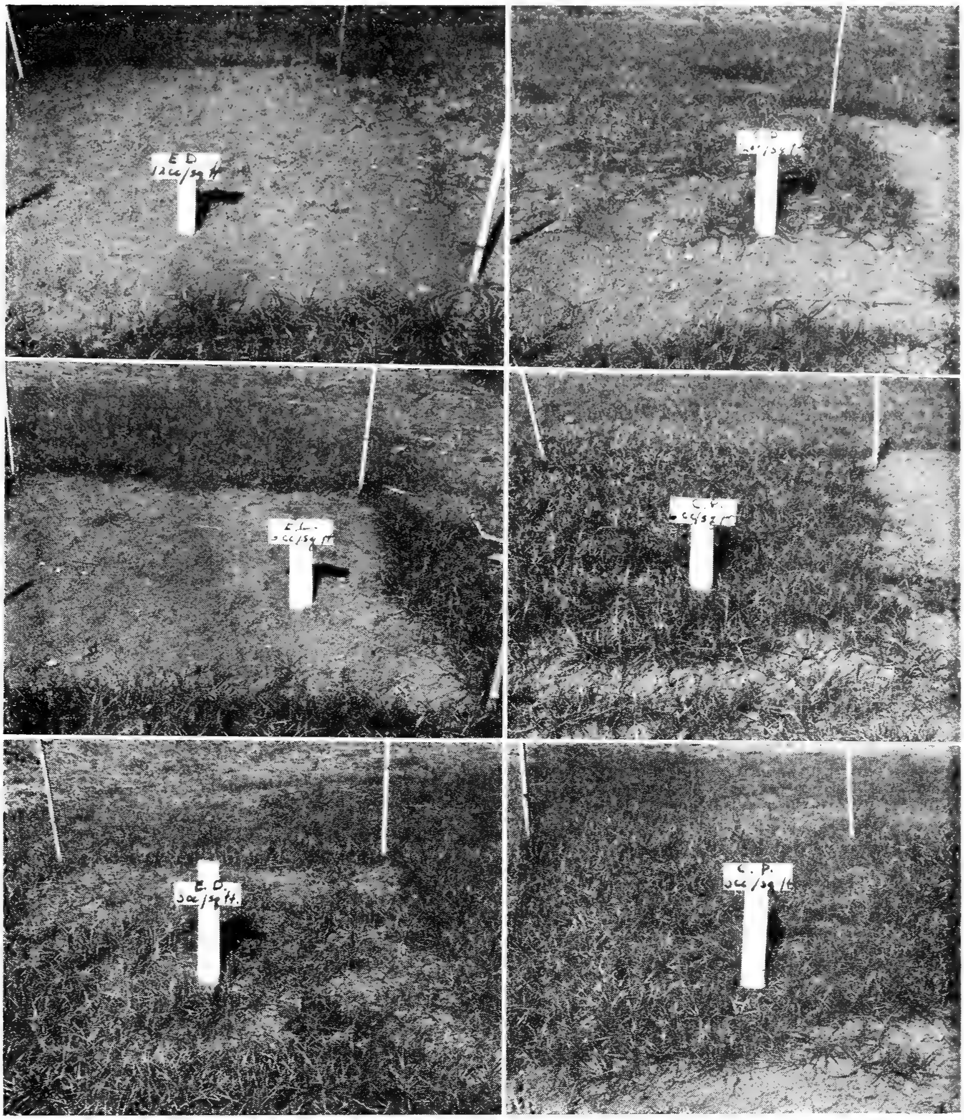

FIGURE 7.—The photographs on the left show plots 4 months after treatment with ethylene dibromide at the rate of 3, 6, and 12 ml. per square foot. Plots on the right were treated with chloropicrin at 3, 6, and 12 ml. per square foot. Note the excellent control with ethylene dibromide at 6 and 12 ml. However, even at the 6-ml. rate, this treatment is too expensive to be practical. Methyl bromide is equally effective and more economical.

feet. Four of the plots were plowed 6 inches deep and the other 4 were not plowed. All the plots were then covered with heavy sisalkraft paper and the borders sealed with soil. Methyl bromide was applied under the cover at the rate of 0, ½, 1, and 2 pounds per 100 square feet. After 48 hours the paper cover was removed. The number of live tubers to a depth of 9 inches was determined in all plots before treatments were applied and 3 months after. The soil temperature at the time of treatment was 27° C. and the air temperature was 32.5° C. Throughout the experimental period soil moisture was adequate.

The data obtained (table 2) showed that ½ to 1 pound of methyl bromide applied to 100 square feet of plowed ground was effective in killing the nutgrass tubers to a depth of 9 inches. The 2-pound rate, which would normally be expected to be at least as effective as the ½- and 1-pound rates, gave less control because some of the fumigant escaped through a hole which was accidentally made in the paper cover at the time the methyl bromide was applied. This accident demonstrates the importance of maintaining well-sealed, gasproof covers over the fumigant. The data also show that much better penetration of the soil results when the land is plowed; treating unplowed soil was ineffective (fig. 8).

TABLE 2.—*Effect of methyl bromide on nutgrass tubers*

Methyl bromide treatment per 100 square feet (pounds)	Soil depth	Initial tuber counts July 3, 1950	Soil preparation	Tuber counts 3 months after treatment [1]	
		Tubers per square foot		Tubers per square foot	Dead tubers
	Inches	*Number*		*Number*	*Percent*
0	0–3	432	Not plowed	291	68
			Plowed	312	11
	3–6	203	Not plowed	56	67
			Plowed	210	18
	6–9	37	Not plowed	15	53
			Plowed	94	15
½	0–3	294	Not plowed	657	51
			Plowed	21	100
	3–6	104	Not plowed	199	36
			Plowed	28	100
	6–9	15	Not plowed	51	14
			Plowed	6	100
1	0–3	319	Not plowed	367	69
			Plowed	152	96
	3–6	44	Not plowed	300	83
			Plowed	184	92
	6–9	10	Not plowed	40	60
			Plowed	99	92
2 [2]	0–3	276	Not plowed	284	71
			Plowed	163	80
	3–6	85	Not plowed	158	82
			Plowed	164	84
	6–9	13	Not plowed	35	85
			Plowed	99	81

[1] Counts were made on Oct. 4, 1950.

[2] At the time the treatment was applied a hole was accidentally made in the paper covering these plots. This allowed some of the fumigant to escape and probably accounts for the incomplete killing of the tubers.

FIGURE 8.—Photograph illustrates the importance of plowing before fumigating the soil with methyl bromide. The plot at the left was plowed to a depth of 6 inches, then treated with methyl bromide at the rate of 1 pound per 200 square feet. The plot at the right was treated at the same rate, but it was not plowed before treatment. The photograph was taken 3 months after treatment.

Experiments with temporary soil sterilants, TCA, and CMU.—Soil sterilants like the chlorates and arsenicals have many disadvantages but if used in sufficient quantities they will kill nutgrass. Sodium chlorate applied at the rate of 4 cwt. per acre proved to be effective in Queensland (*50*). A significant initial reduction in stand was obtained with TCA (sodium trichloroacetate) in Louisiana (*12*), but no permanent reduction of tubers was found in the soil.

Both TCA and CMU (3-[para-chlorophenyl]-1,1-dimethylurea) were tested at this station in the following experiments to control nutgrass. In 1 experiment TCA was applied at the rate of 218 pounds per acre to 4 plots. One-half the amount was applied to 2 of the plots; the land was then disked, and the remaining half of the herbicide was applied. In the other 2 plots the full amount of herbicide was sprayed directly on the undisturbed nutgrass.

Two months later the plots that had been disked and treated with TCA were free of nutgrass and other vegetation, but the undisturbed and treated plots had considerable nutgrass which was chlorotic and unthrifty. Examination of the soil showed that 80 percent of the tubers had been killed in the disked and treated plots, but that enough live tubers remained to reinfest the area.

To study the effect of TCA on tubers located at different depths in the soil the following experiment was carried out under greenhouse conditions where environmental factors could be controlled better.

Mature tubers were selected from a plowed field and divided into lots of 50 tubers each. Five-gallon earthenware jars (coffee urns) were filled with a uniform mixture of screened soil, free of nutgrass tubers. Duplicate sets of jars were each planted with 50 tubers at the following depths: 1, 2, 4, 6, 8, 10, 12, 15, 20, 25, 30, and 35 inches below the soil surface. (Steel drums 36 inches high were used as

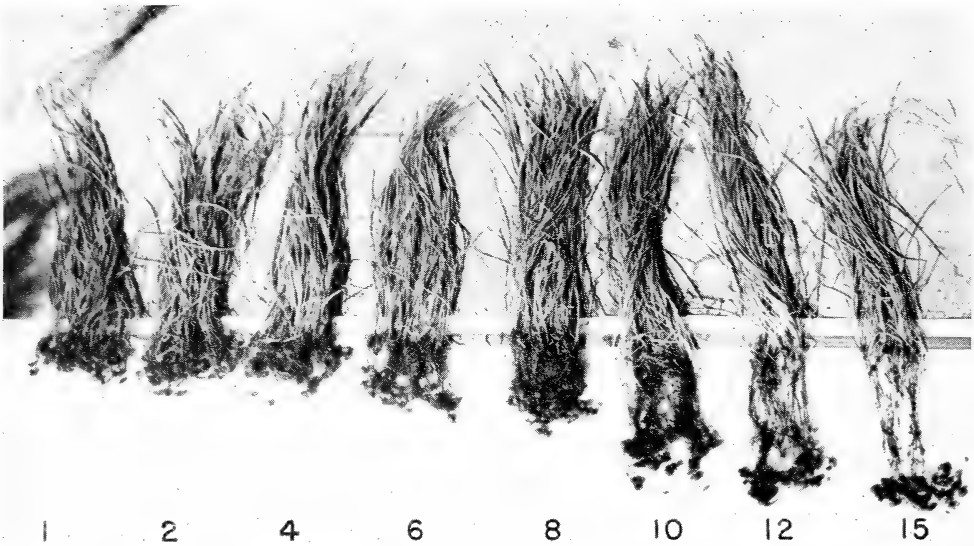

FIGURE 9.—Nutgrass plants that developed from tubers planted in the soil at depths of 1, 2, 4, 6, 8, 10, 12, and 15 inches. The plants were harvested 4 months after planting. Note that the height of the shoots is about the same regardless of the depth at which the tubers were planted.

containers for the last four plantings.) After planting, the required depth of soil was placed on top of the tubers, firmed gently without packing, and watered to field capacity or until excess water drained from the holes at the bottom of the jars. One member of each pair of jars was treated with a solution of sodium TCA at the rate of 100 pounds per acre. At intervals of 1 week, or when needed, 1/4 inch of water was added to all jars. Emergence counts were taken at intervals ranging from 5 to 133 days after the tubers were planted.

As might be expected, the time and percentage of emergence of nutgrass seedlings in the untreated jars was correlated with the depth at which they were planted. Of those planted 1 inch below the surface, more than 50 percent emerged within 5 days after planting and almost all had emerged by the eighth day. Of those planted at 2 and 4 inches below the surface almost all had emerged by the twelfth day. On the eighteenth day a majority of the tubers planted at 6- and 8-inch depths had emerged, whereas 24 and 37 days, respectively, were required for the majority of tubers planted at 10- and 12-inch depths to emerge. Fifty percent of the tubers planted at 15-inch depth emerged after 37 days and all had emerged in 60 days. Of those planted at 20-inch depth, 3 seedlings emerged after 18 days and no more had emerged at the end of 133 days. Of those planted at 25, 30, and 35 inches, 1, 2, and 2 seedlings, respectively, emerged 37 days after planting and no more had emerged at the end of 133 days. Figure 9 shows the plants that developed from tubers planted 1 to 15 inches deep in untreated soil.

In the treated jars with tubers planted at 4- to 12-inch depth, 1 to 15 seedlings emerged between the 8th and 18th day after planting, but all of these soon withered and died as they came in contact with the TCA in the soil; by the 37th day all the treated jars were free from nutgrass seedlings and remained that way for over 3 months. How-

ever, by the end of 133 days, from 3 to 28 seedlings had developed in the treated jars regardless of depth of planting (from 1 to 15 inches). There was no consistent relationship between depth of planting in treated jars and the number of seedlings which finally emerged after 133 days.

The results of this experiment indicate that mature nutgrass tubers germinate, and that about 100 percent of the young seedlings emerge even when the tubers are located 15 inches below the surface of the soil. However, the time required for emergence is directly correlated with the depth at which the tubers are located in the soil. When the tubers are located 20 inches or deeper below the surface the emergence of young sprouts is greatly inhibited, but 2 to 6 percent of the tubers sprouted 37 days after planting, and this is probably enough eventually to infest an area. Treatment of the soil surface with sodium TCA at 100 pounds per acre inhibited the growth of tubers planted at all depths for a period of 3 months, but at the end of 133 days, 6 to 56 percent of the tubers had produced shoots regardless of depth of planting from 1 to 15 inches. By this time the TCA had been either leached or inactivated and apparently some buds on some tubers were still alive. The data obtained in this study help to explain some of the erratic results obtained in the field trials.

To obtain additional information on the effect of TCA on germination of nutgrass tubers, mature tubers were selected from a field collection, divided into 77 lots of 30 tubers each, and immersed for 5, 10, 20, 40, 80, 160, and 320 minutes in solutions of sodium TCA of the following concentrations: 0, 10, 50, 100, 190, 380, 750, 1,500, 3,000, 6,000, and 12,000 p. p. m. After immersion the tubers in each treatment were divided into three replicates of 10 each and these were planted, without washing, in moist soil. Counts of young sprouts were made 5 weeks after planting.

Germination of tubers was inhibited somewhat by immersion in the TCA solutions particularly in those of high concentrations and at the long exposures, but in no instance was it completely inhibited. Under field conditions there is an initial reduction in stand of nutgrass caused primarily by the toxic action of the herbicide on stem, leaf, and bud portions of the plants. As long as lethal concentrations of TCA remain in the soil, new plants which arise from buds on the tubers are killed. However, after the toxicity of TCA disappears because of leaching or inactivation, there are usually one or more live buds remaining on the nutgrass tubers and these sprout and reestablish the stand. If TCA is applied at the rate of 100 pounds per acre and this is uniformly distributed in the surface 6 inches of an acre of soil, the concentration of TCA would be about 50 p. p. m. In the present experiment, exposure of the tubers to a concentration of 12,000 p. p. m. for over 5 hours did not kill all the buds on the tubers.

Since CMU, 3 para-chlorophenyl-l, 1 dimethylurea, has been shown to be an unusually potent herbicide that persisted in the soil for long periods of time (*30*), it was tested in the following experiments to control nutgrass.

A flat area with a heavy stand of nutgrass was divided into 2 randomized blocks with 4 treatments each. One block was plowed to a depth of 6 inches and the other block was left undisturbed. CMU was

applied in the form of 80-percent wettable powder with a knapsack sprayer at the rate of 0, 20, 40, and 80 pounds per acre to plots in each block.

The number of live tubers in samples of soil at 3-inch intervals, to a depth of 9 inches, was determined before the treatments were started and 5½ months after the herbicide was applied. Although there was a reduction of 80 to 90 percent in the number of live tubers at the 80-pound rate enough live tubers remained in the soil to reinfest it. This experiment showed that although a single application of CMU at relatively high rates reduced the infestation of nutgrass it did not eradicate it.

The results of the foregoing experiment with CMU suggested that the depth at which the tubers were located in the soil might determine the effectiveness of CMU application. The following experiment was conducted to study the effect of CMU on tubers located at different depths in the soil. It was carried out under greenhouse conditions where environmental factors could be better controlled.

Mature, healthy tubers were collected from a plowed field and divided at random into lots of 20 tubers each. Five-gallon earthenware jars (coffee urns) were filled with a uniform mixture of screened soil free of nutgrass tubers. Duplicate sets of jars were planted with 20 tubers each at depths of 1, 2, 4, 6, 8, 10, 12, and 14 inches below the surface. After planting, the required depth of soil was placed on top of the tubers and firmed gently without packing. All jars were watered to field capacity and one member of each pair of jars was treated with CMU at the rate of 40 pounds per acre. The required amount of CMU was dispersed in water and sprayed on the surface of the soil. After the treatments were applied, the jars were watered as needed with the equivalent of ¼ inch of water. Five and one-half months later the soil was washed from the jars and the number of live and dead tubers counted. The average fresh weight of the live tubers was also determined. These data are presented in table 3.

TABLE 3.—*Effect of soil surface treatment with CMU on growth and propagation of nutgrass tubers planted 1 to 14 inches in depth* [1]

Planting depth of 20 tubers Jan. 11, 1952 (inches)	Shoots per jar		Tubers per jar				Total fresh weight of tubers per jar		Average weight per tuber	
			Alive		Dead					
	Check	Treated	Check	Treated	Check	Treated	Check	Treated	Check	Treated
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Grams*	*Grams*	*Milligrams*	*Milligrams*
1	53	0	184	0	0	11	54. 1	0	294	0
2	48	0	234	0	0	15	64. 5	0	275	0
4	45	11	223	31	0	11	52. 2	2. 4	234	77
6	62	3	215	22	0	13	50. 8	3. 9	236	177
8	47	5	235	15	1	17	55. 0	2. 8	234	186
10	33	9	141	15	0	18	23. 5	3. 2	166	213
12	45	6	130	8	4	18	22. 1	2. 6	170	325
14	30	16	155	59	1	10	31. 4	9. 0	202	152

[1] Data obtained June 27, 1952, 5 months after planting and treatment.

Tubers planted 1 to 8 inches below the surface of untreated soil increased 9- to 11-fold during 5½ months. Those planted 10 to 14 inches below the surface of untreated soil increased 7- to 8-fold during the same period. All tubers appeared healthy regardless of depth of planting, but the tubers developed from those planted 1 to 8 inches below the surface were larger and heavier than those developed from tubers planted 10 to 14 inches deep.

Tubers planted 1 and 2 inches below the surface of treated soil were completely eradicated. Those planted at a 4-inch depth increased in numbers, but they were very small and shriveled as evidenced by the average weight per tuber (77 mg.), compared with that of the corresponding check tubers (234 mg.). Tubers planted 6 to 12 inches below treated soil showed little or no increase in numbers during the 5½ months, but instead there was considerable decrease at most planting depths. However, as the planting depth increased the size and weight of the surviving tubers increased. Tubers planted 14 inches below treated soil increased threefold in number, and these appeared healthy though somewhat smaller than the corresponding check tubers.

These data show that CMU can eradicate nutgrass tubers within 2 and possibly 4 inches of the soil surface. They also show that CMU has a strong inhibitory effect on tubers planted as deep as 14 inches below the surface. However, the deeper the tubers are located the better chance they have of surviving the effects of the CMU. Eventually the toxicity of the CMU is dissipated and the deep tubers can sprout and reinfest an area. Therefore an effective program of eradication should include repeated deep plowings to bring the tubers to the surface, followed by CMU treatment.

The experiments described showed that high rates (80 pounds per acre) of CMU greatly reduced the population of nutgrass tubers in the soil but did not eradicate them. Field and greenhouse studies indicated that (1) CMU remained near the surface of the soil regardless of the amount of rainfall, and (2) the tubers located deep in the soil are protected somewhat from the toxic action of CMU sprayed on the soil surface. Thus, the tubers located deep in the soil do not come in contact with the herbicides and remain viable. In view of this fact, an experiment was planned in which relatively low rates of CMU were combined with alternate plowings to bring the nutgrass tubers in contact with the herbicide. Plots treated with 2,4-D and TCA were also included in the experiment for comparison.

Plots 30 x 15 feet of plowed and disked Toa silty clay soil heavily infested with nutgrass were sprayed in May with the following formulations: 40 and 20 pounds of CMU per acre; 20 pounds of CMU, 20 pounds of TCA; 20 pounds of CMU, 20 pounds of TCA, 5 pounds of 2,4-D; 20 pounds of CMU, 5 pounds of 2,4-D; 40 pounds of TCA; 5 pounds of 2,4-D. Two control plots were included, 1 plowed and 1 not plowed. Six weeks after the herbicides were applied the treated plots were plowed and treated again at the indicated rates. After 14 weeks one-half of each treated plot was plowed and again treated. Counts of live tubers to a depth of 12 inches were made in December.

The data presented in table 4 show that 6 months after the initial treatment all plots in which CMU was applied either alone or in

combination with 2,4-D and TCA had only a few live tubers remaining. On the other hand, check plots and those treated with TCA had over 600 tubers per cubic foot, and plots treated with 2,4-D had 250 tubers per cubic foot.

TABLE 4.—*Counts of live nutgrass tubers per cubic foot of soil, 6 months after treatment with CMU, TCA, or 2,4-D, alone and combined*

Treatments	2 plowings, 6 weeks apart, each followed by application at indicated rate	3 plowings, 6 and 8 weeks apart, each followed by application at indicated rate
	Tuber counts per cubic foot	Tuber counts per cubic foot
	Number	*Number*
Control (plowed)	501	(2)
Control (not plowed)[1]	621	(2)
40 pounds/acre CMU	7	4
20 pounds/a CMU	23	5
20 pounds/a CMU 20 pounds/a TCA	5	3
20 pounds/a CMU 20 pounds/a TCA 5 pounds/a 2,4–D	25	5
20 pounds/a CMU 5 pounds/a 2,4–D	3	2
40 pounds/a TCA	735	615
5 pounds/a 2,4–D	131	250

[1] Average number tubers per cubic foot at start of experiment 170.
[2] No data taken.

The results of this experiment demonstrate that two applications of CMU at relatively low rates each preceded by plowing is more effective in killing nutgrass tubers than a single application of CMU at a high rate. Figure 10 shows a plot treated twice with 20 pounds per acre of CMU and plowed before each application. The photograph was taken 4 months after the last plowing.

SUMMARY

Studies on the life history of nutgrass showed that this plant resembles others in many of its characteristics. These basic investigations are discussed in detail in the section on morphogenesis. From the standpoint of control, it was particularly important to know that tubers separated from the chain sprouted at equal rates and that light stimulated sprouting. New tubers were formed within 3 weeks after sprouting. These results suggested that control methods should consist of disturbing the underground system as much as possible to bring the tubers to the surface and to induce maximum sprouting before treatment. Treatment should be applied within a few weeks after the first sprouts appear.

The most reliable method of determining the degree of infestation or control is to count the number of live tubers to a depth of 9 to 12 inches in the soil. A false estimate of the nutgrass population is often given by counting only the shoots.

FIGURE 10.—Shows the good control of nutgrass achieved with two applications of CMU each at 20 pounds per acre, preceded by two plowings 6 weeks apart. The photograph was taken 4 months after the last plowing. Examination of the soil to a depth of 12 inches showed only an occasional live tuber. Note the nutgrass in the foreground on a plowed but untreated plot.

The effect of several chemicals in controlling nutgrass was tested. The results obtained have been discussed under the appropriate sections and are summarized here.

Repeated treatment of shoots with 2,4-D over a long period of time during which the ground remained fallow reduced but did not eradicate the tubers. 2,4-D was more effective when applied after the ground had been plowed than when it was applied first and later mixed with the soil. 2,4-D was also more effective when it was applied to the soil a few weeks after the land had been plowed. Temporary control of the nutgrass shoots in corn and sugarcane was achieved by spraying the growing weeds with 0.2 percent 2,4-D. The ester formulation was found to be better for killing the shoots than the sodium or amine salts, but the salt formulations were more effective in killing the tubers in plowed soil. One disadvantage in the continuous use of 2,4-D is that it frequently encourages resistant and more troublesome weeds like Bermuda grass to become the dominant species. 2,4,5-T was much less effective than 2,4-D in controlling nutgrass.

A rapid-growing forage crop like velvetbeans was grown successfully without weed control in a moist area heavily infested with nutgrass. However, the nutgrass was not eradicated, but only suppressed during the time the legume was present.

Of the three fumigants tested—chloropicrin, ethylene dibromide, and methyl bromide—the last was by far the best from the standpoint of effectiveness and economy. One-half pound applied to 100 square feet of plowed soil covered with a gastight cover for 48 hours killed all the nutgrass tubers to a depth of 9 inches. Although this method

is not practical for large-scale application, it is well suited to small vegetable or garden plots. The method has the very desirable advantage that the land can be planted within a week or so after treatment and also that many soil-borne insects and diseases are killed by it.

Of the temporary soil sterilants tested, the most effective one to date is CMU. Control, approaching eradication, was obtained by alternately plowing and treating the soil with CMU at the rate of 20 pounds per acre. At least 2 plowings and 2 applications of CMU were required for practical eradication of nutgrass. The main disadvantage of this method, other than the cost, is that CMU persists in the soil for several months and the land must lie fallow for an extended period of time before crops can be planted.

Pentachlorophenate applied at the rate of 30 pounds per acre at monthly intervals for 3 months greatly reduced the number of tubers in the soil but did not eradicate them.

TCA applied at relatively high rates (over 200 pounds per acre) was only partly effective in killing the tubers. TCA has the disadvantage that it leaches rapidly and does not persist long enough in the soil to be effective.

Repeated plowing under humid, tropical conditions increased the nutgrass population in the soil.

LITERATURE CITED

(1) ANAND, INDIA. INSTITUTE OF AGRICULTURE.
1944. THE FOURTH ANNUAL REPORT OF THE GOVERNING BODY OF THE INSTITUTE OF AGRICULTURE, ANIMAL HUSBANDRY AND DAIRYING, ANAND, INDIA. Inst. Agr. Gen. Ser. Bul. 4: 35.

(2) ANDREWS, F. W.
1940. THE CONTROL OF NUT GRASS IN THE SUDAN GEZIRA. Empire Jour. Expt. Agr. 8: 215–222, illus.

(3) ANONYMOUS.
1948. NUT GRASS CONTROL. Fiji Dept. Agr., Agr. Jour. 19: 29–30.

(4) ASENJO, C. F.
1937. APUNTES ACERCA DE LAS PLANTAS MEDICINALES DE PUERTO RICO. *In* Puerto Rico. Univ. School of Trop. Med., Collected papers 10: 1–14.

(5) BUCKLEY, T. A.
1951. NOTES ON THE CONTROL OF TREES AND WEEDS BY PHYTOCIDES. Malayan Agr. Jour. 34: 27–31.

(6) BURGIS, D. S.
1949. CONTROL OF NUTGRASS WITH 2,4-D. Market Growers Jour. 78 (8): 9, 22.

(7) ———
1951. NUTGRASS CONTROL WITH 2,4-D IN FLORIDA. Fla. Agr. Expt. Sta. Cir. S–38: 5 pp., illus.

(8) ———
1951. NUTGRASS CONTROL WITH 2,4-D. *In* 4th South. Weed Conf. Proc., Memphis, Tenn., pp. 24–25. Feb. 8–9, 1951.

(9) ———, and SPENCER, E. L.
1947. HERBICIDES GIVE CONTROL OF CERTAIN WEEDS IN VEGETABLE SEEDBEDS. Market Growers Jour. 76 (8): 13, 49.

(10) CIFERRI, R.
1931. AN INTERNATIONAL ENQUIRY ON THE BIOLOGICAL AND ARTIFICIAL CONTROL MEASURES OF NUTGRASS (CYPERUS ROTUNDUS). Internatl. Rev. Agr. 22 (8): M–143–145.

(11) COLOMBIA. DEPT. NAC. DE AGR.
1947. REPORT FOR 1947. Bogotá. p. 271.

(12) COWART, L. E., and RYKER, T. C.
1950. STUDIES ON THE CONTROL OF NUTGRASS (CYPERUS ROTUNDUS). *In* 3rd South. Weed Conf. Proc., Biloxi, Miss., pp. 135–139. Feb. 7–8, 1950.

(13) ————, [illegible], T. C., and Creasey, L. E.
1949. STUDIES ON CHEMICAL CONTROL OF NUTGRASS. *In* 2nd South. Weed Conf. Proc., Baton Rouge, La., pp. 61–62. Jan. 31–Feb. 2, 1949.

(14) Dalziel, J. M.
1937. THE USEFUL PLANTS OF WEST TROPICAL AFRICA. London.

(15) Dass, C. M.
1946. THE CONTROL OF NUTGRASS BY MEANS OF COVER CROPS. Fiji Dept. Agr., Agr. Jour. 17: 58–59.

(16) Davis, C. H.
1942. RESPONSE OF CYPERUS ROTUNDUS L. TO FIVE MOISTURE LEVELS. Plant Physiol. 17: 311–316.

(17) ————, and Hawkins, R. S.
1943. ERADICATION AND CONTROL OF NUTGRASS. Ariz. Agr. Expt. Sta. Bul. 189: 20 pp., illus.

(18) Day, B. E.
1953. SOIL FUMIGATION WITH CHLOROBROMOPROPENE FOR THE CONTROL OF NUTGRASS. Hilgardia 21: 593–603, illus.

(19) Domato, J., and Aramayo, H.
1947. LAS HORMONAS Y SUS POSIBLES APLICACIONES EN LA AGRICULTURA. [HORMONES AND THEIR POSSIBLE APPLICATIONS IN AGRICULTURE.] Tucumán, Argentine Repub. (City) Est. Expt. Agr. Bol. 62: 20 pp., illus.

(20) Eames, A. J.
1949. COMPARATIVE EFFECTS OF SPRAY TREATMENTS WITH GROWTH REGULATING SUBSTANCES ON THE NUTGRASS, CYPERUS ROTUNDUS L., AND ANATOMICAL MODIFICATIONS FOLLOWING TREATMENT WITH BUTYL 2,4-DICHLOROPHENOXYACETATE. Amer. Jour. Bot. 36: 571–584, illus.

(21) ————
1949. HISTOLOGICAL EFFECTS OF TREATMENTS WITH GROWTH REGULATING SUBSTANCES OF THE 2,4-D GROUP. Science 110: 235–236, illus.

(22) Fromm, F.
1942. THE ERADICATION OF NUTGRASS. Science 96: 337–338.

(23) Godfrey, G. H.
1939. THE CONTROL OF NUTGRASS WITH CHLOROPICRIN. Soil Sci. 47: 391–395, illus.

(24) Harrison, A. L.
1946. 2,4-D FOR THE CONTROL OF NUTGRASS. Fla. State Hort. Soc. Proc. 59: 78–81.

(25) Hutchinson, J., and Dalziel, J. M.
1936. FLORA OF WEST TROPICAL AFRICA. v. II, pt. 2, London.

(26) Justice, O. L., and Whitehead, M. D.
1946. SEED PRODUCTION, VIABILITY, AND DORMANCY IN THE NUTGRASSES, CYPERUS ROTUNDUS AND C. ESCULENTUS. Jour. Agr. Res. 73: 303–318.

(27) Leonard, O. A., and Harris, V. C.
1950. NUTGRASS CONTROL WITH METHYL BROMIDE. *In* 3rd South. Weed Conf. Proc., Biloxi, Miss., pp. 132–134. 1950.

(28) ————, Harris, V. C., and Edwards, F. E.
1950. THE CONTROL OF JOHNSON GRASS IN SOYBEANS WITH LHH-1. *In* 3rd South. Weed Conf. Proc., Biloxi, Miss., p. 49. 1950.

(29) Loustalot, A. J.
1948. PROGRESS REPORT ON WEED CONTROL. *In* 1st South. Weed Conf. Proc., Stoneville, Miss., pp. 7–10. June 10, 1948.

(30) ————, Muzik, T. J., and Cruzado, H. J.
1953. A STUDY OF THE PERSISTENCE OF CMU IN SOIL. Agr. Chem. 8: 52–53, 97–101.

(31) Malkov, F. I.
1936. PRINCIPAL WEEDS OF THE TURKOMAN S. S. R. AND MEANS OF CONTROLLING THEM [trans. title]. Trudy Prikl. Bot., Genet., i Selek. (Bul. Appl. Bot., Genet., Plant Breeding) ser. 9, No. 5, Sup. 80, 48 pp., illus.

(32) Mayton, E. L., Smith, E. V., and King, D.
1945. NUT GRASS ERADICATION STUDIES—IV. USE OF CHICKENS AND GEESE IN THE CONTROL OF NUT GRASS, CYPERUS ROTUNDUS L. Amer. Soc. Agron. Jour. 37: 785–791.

(33) MUZIK, T. J., and CRUZADO, H. J.
1953. THE EFFECT OF 2,4-D ON SPROUT FORMATION IN CYPERUS ROTUNDUS. Amer. Jour. Bot. 40: 507–512.

(34) NOLLA, J. A. B.
1948. CONTROL OF GRASS WEEDS IN SUGARCANE FIELDS IN PUERTO RICO. Science 108: 112–113.

(35) ORSENIGO, J. R., and SMITH, O.
1953. THE CHEMICAL CONTROL OF NORTHERN NUTGRASS, CYPERUS ESCULENTUS L. In 7th Northeast. Weed Control Conf. Proc., New York, N. Y., pp. 329–339. Jan. 7–9, 1953.

(36) PARHAM, B. E.
1940. NOTES ON WEEDS IN FIJI-IV. Fiji Dept. Agr., Agr. Jour. 11: 101–103.

(37) PILLAY, R. A.
1944. NUT GRASS AND ITS ERADICATION. Indian Farming 5: 67–68.

(38) SCHULTZ, E. F.
1942. LA EXTIRPACIÓN DEL "CEBOLLÍN", "TOTORILLA" O "JUNCEA." [THE ERADICATION OF NUT GRASS (CYPERUS ROTUNDUS L.).] Rev. Indus. Agr. Tucumán 32: 163–164.

(39) SMITH, E. V., and FICK, G. L.
1937. NUT GRASS ERADICATION STUDIES.—I. RELATION OF THE LIFE HISTORY OF NUT GRASS, CYPERUS ROTUNDUS L., TO POSSIBLE METHODS OF CONTROL. Amer. Soc. Agron. Jour. 29: 1007–1013, illus.

(40) ————, and MAYTON, E. L.
1938. NUT GRASS ERADICATION STUDIES.—II. THE ERADICATION OF NUT GRASS CYPERUS ROTUNDUS L., BY CERTAIN TILLAGE TREATMENTS. Amer. Soc. Agron. Jour. 30: 18–21.

(41) ————, and MAYTON, E. L.
1942. NUT GRASS ERADICATION STUDIES.—III. THE CONTROL OF NUTGRASS, CYPERUS ROTUNDUS L., ON SEVERAL SOIL TYPES BY TILLAGE. Amer. Soc. Agron. Jour. 34: 151–159.

(42) SPAFFORD, W. J.
1947. FARMERS FIGHTING LOSING BATTLE AGAINST WEEDS. Jour. Dept. Agr. S. Austral. Dept. Agr. Jour. 51: 116–120.

(43) SUBBIAH MUDALIAR, V. T., and RAMASWAMY AYYAR, S.
1945. ERADICATION OF NUT GRASS. Indian Farming 6: 117–118.

(44) SUMMERVILLE, W. A. T.
1933. TWO INSECT ENEMIES OF NUTGRASS. Queensland Agr. Jour. 40: 284–287.

(45) TALLEY, P. J.
1950. A PROPOSED METHOD FOR THE CONTROL OF WEEDS AND GRASS IN COTTON. *In* 3rd South. Weed Conf. Proc., Biloxi, Miss., pp. 103–113. 1950.

(46) VAN OVERBEEK, J.
1947. USE OF SYNTHETIC HORMONES AS WEED KILLERS IN TROPICAL AGRICULTURE. Econ. Bot. 1: 446–459, illus.

(47) ————, GREGORY, L. E., and VÉLEZ, I.
1946. THE USE OF 2,4-D AS A SELECTIVE HERBICIDE IN THE TROPICS, WITH SPECIAL REFERENCE TO THE CULTURE OF SUGAR CANE. Amer. Soc. Hort. Sci. Proc. 47: 434–438, illus.

(48) VÉLEZ, I., and VAN OVERBEEK, J.
1950. PLANTAS INDESEABLES EN LOS CULTIVOS TROPICALES. Univ. Puerto Rico Press, Rio Piedras, P. R., 497 pp., illus.

(49) WEST, E.
1947. WEED KILLERS. [NUT GRASS (CYPERUS ROTUNDUS) CONTROL]. Fla. Agr. Expt. Sta. Rept.: p. 96.

(50) WINDERS, C. W.
1947. NOTES ON WEED CONTROL. Queensland Agr. Jour. 65: 115–121.

U. S. GOVERNMENT PRINTING OFFICE: 1954